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Nielson

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(54) **CONNECTOR FOR MULTIPLE CORE OPTICAL FIBER**

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G02B 6/36 (2006.01)
G02B 6/38 (2006.01)

(52) **U.S. Cl.**
CPC ***G02B 6/3871*** (2013.01); ***G02B 6/3821*** (2013.01)

(58) **Field of Classification Search**
CPC combination set(s) only.
See application file for complete search history.

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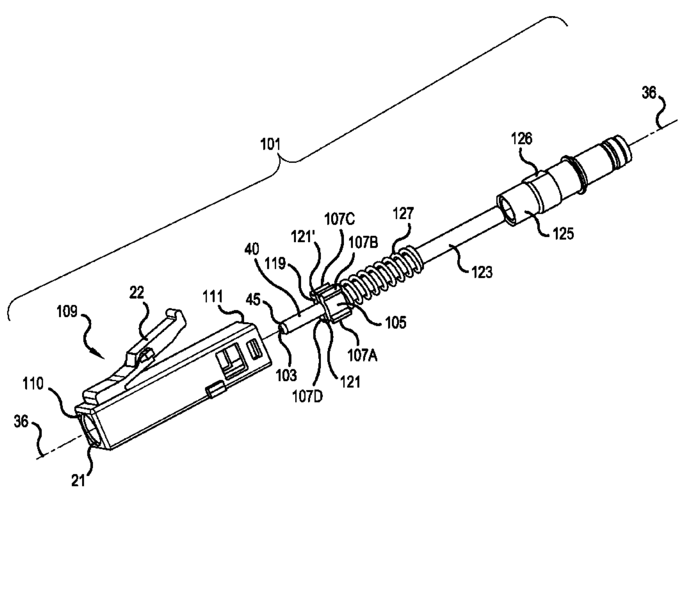
(57) **ABSTRACT**

A fiber optic plug, suitable for multi-core fiber (MCF), is structured to hold satellite cores of the MCF in a precise angular positions so as to attain suitable alignment with satellite cores of a mating connector. The plug includes features to permit a ferrule holding the MCF to move longitudinally relative to the connector's housing, so that a spring may control a mating force to an abutting ferrule of a mating connector. The ferrule may be held by ferrule barrel having splines projecting away from an outer peripheral surface. The splines may slide longitudinally within notches of the connector housing or a strength member attached to the connector housing. The notches and splines have a tight tolerance, so that the satellite cores remain in a desired, set angular position.

20 Claims, 16 Drawing Sheets



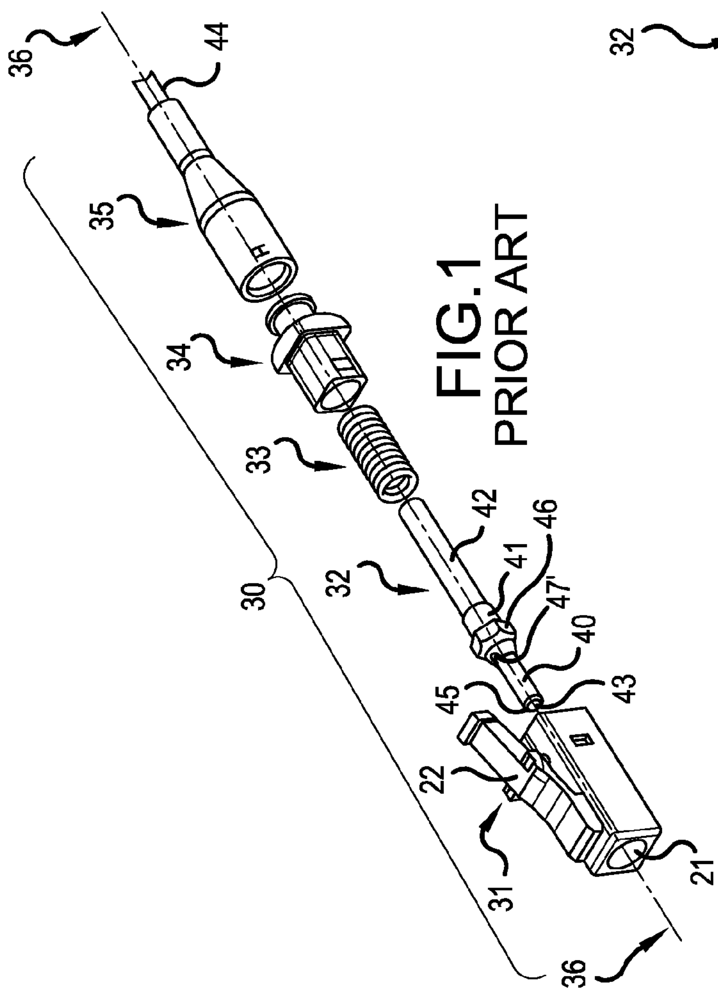


FIG.1
PRIOR ART

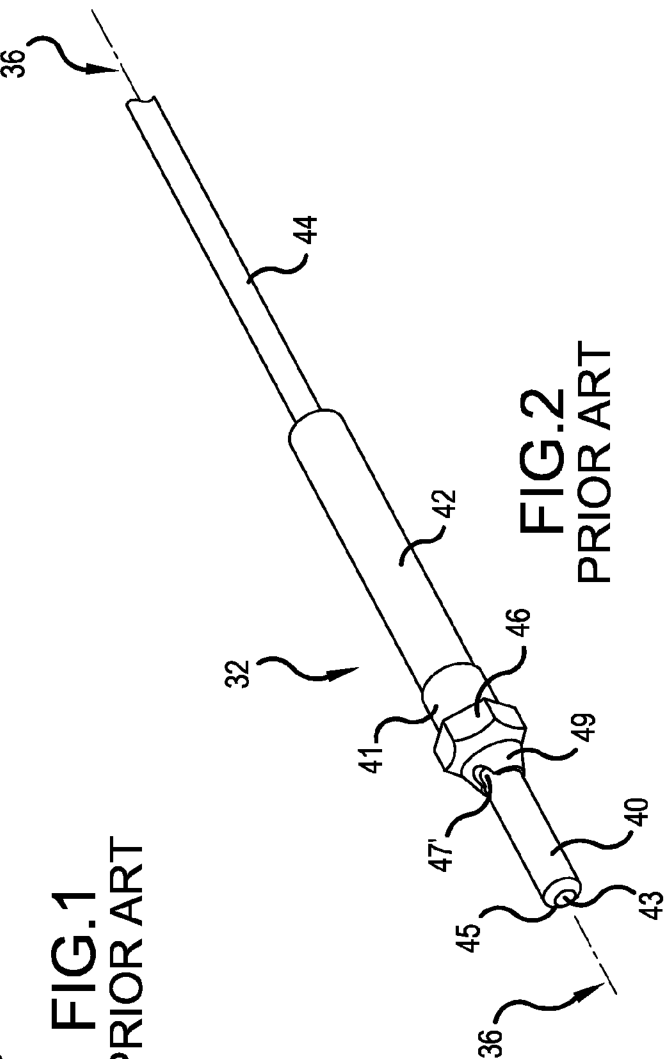


FIG.2
PRIOR ART

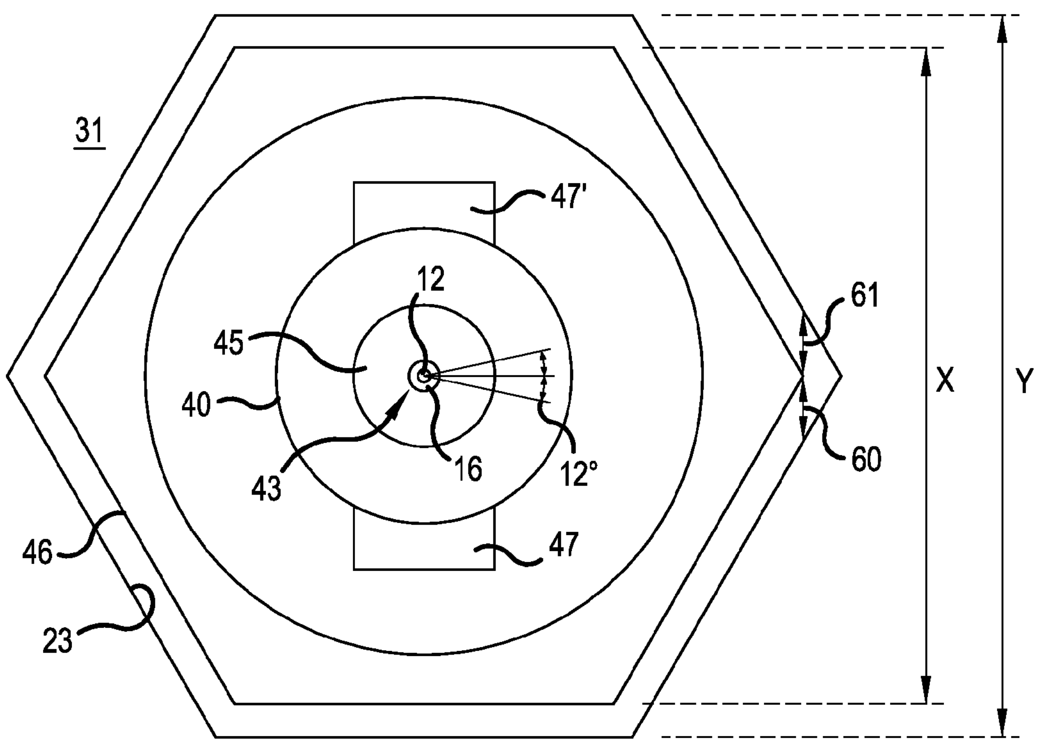


FIG.3
PRIOR ART

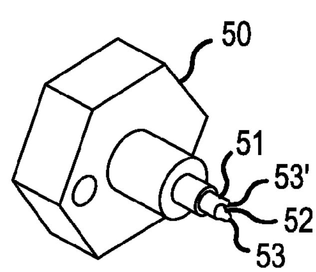


FIG.4
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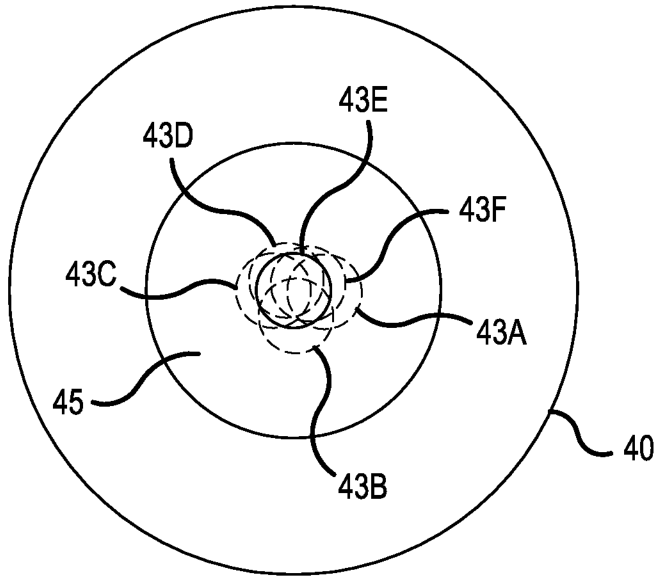


FIG.5
PRIOR ART

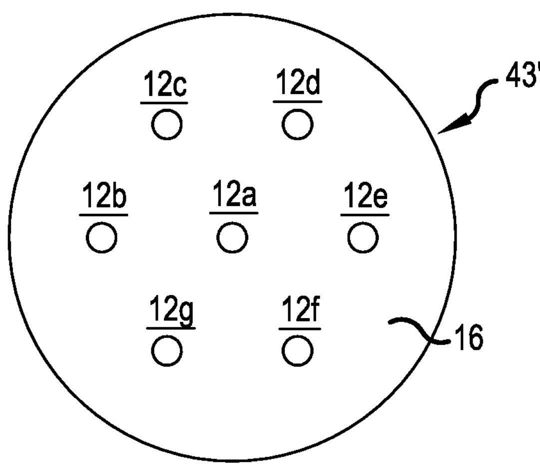
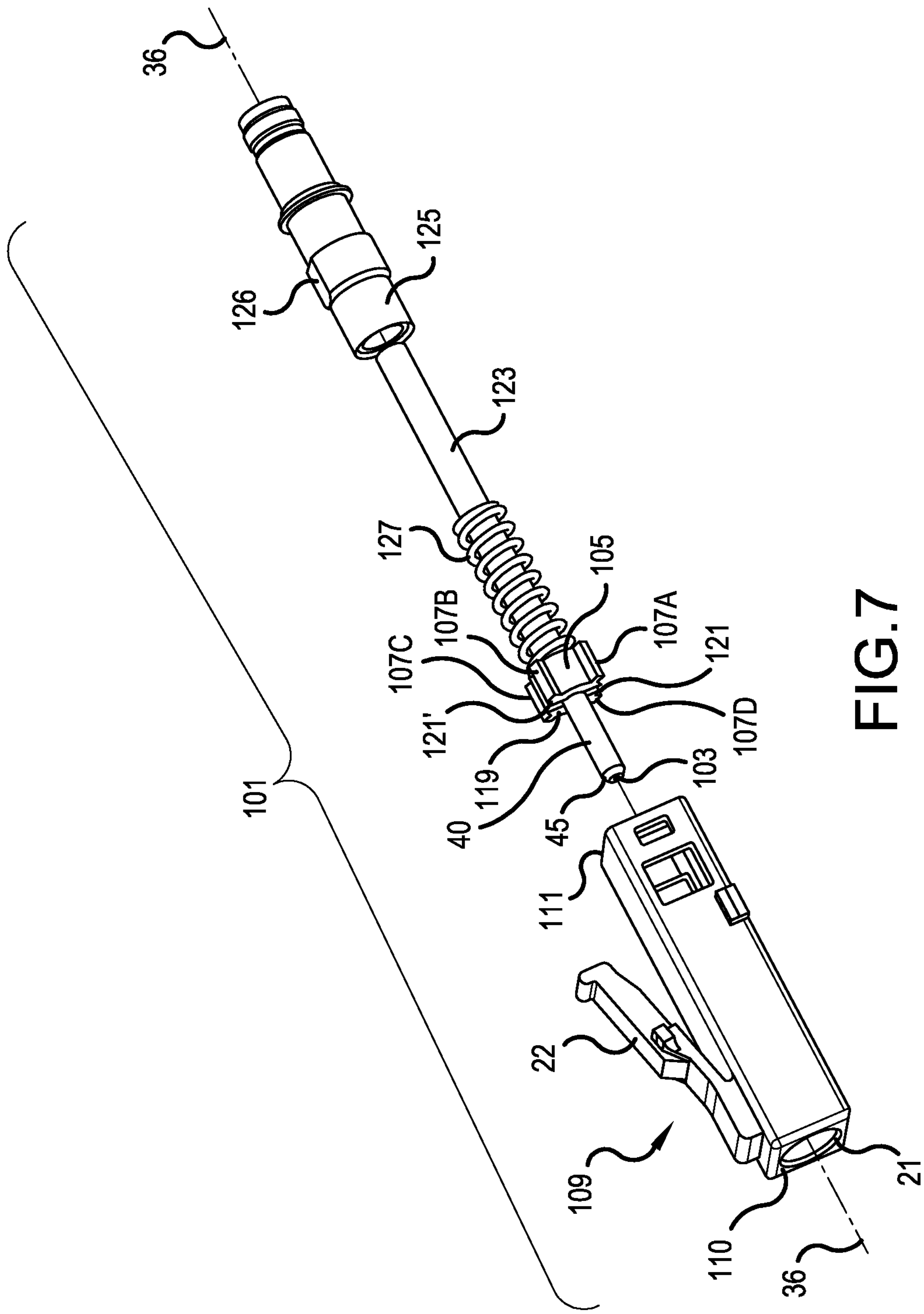


FIG.6
PRIOR ART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36

FIG.7

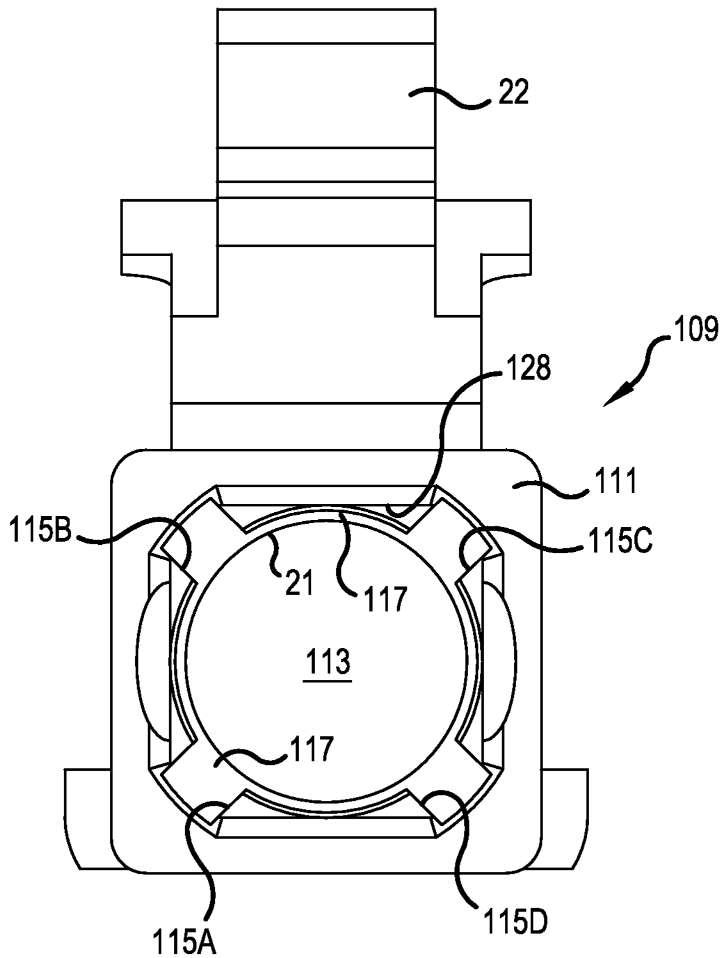


FIG.8

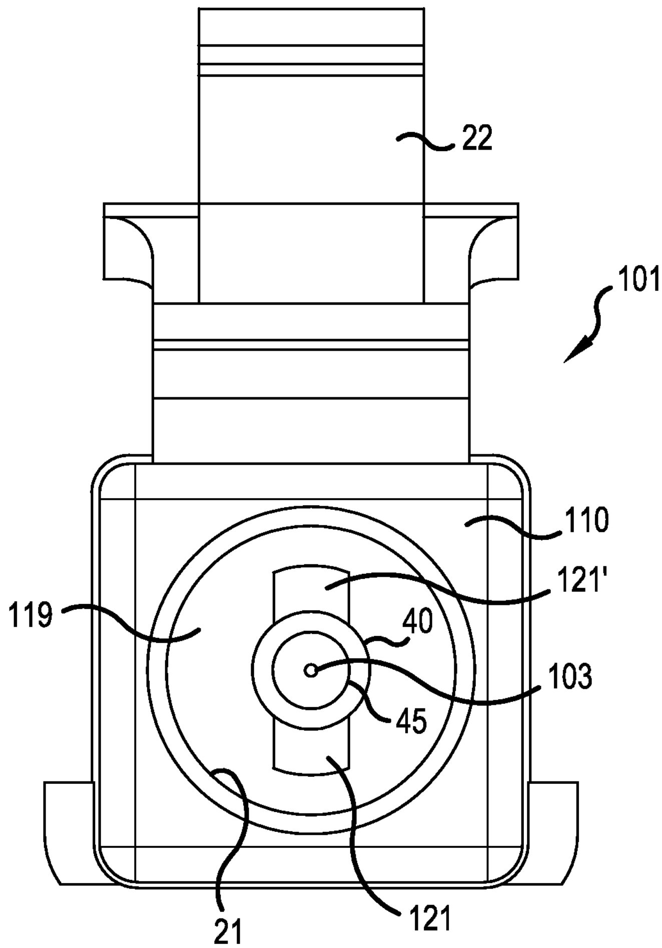
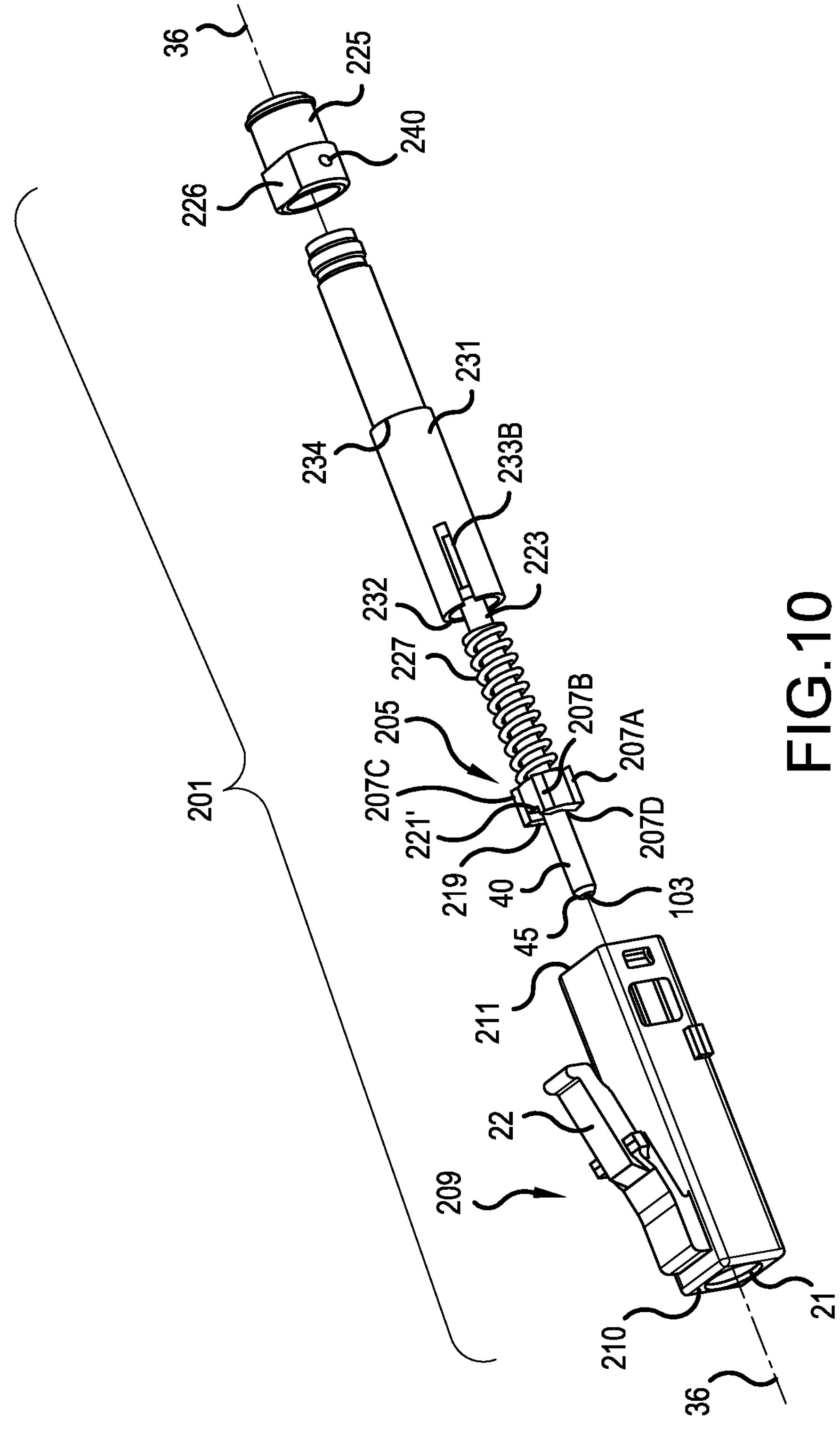


FIG.9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36

FIG.10

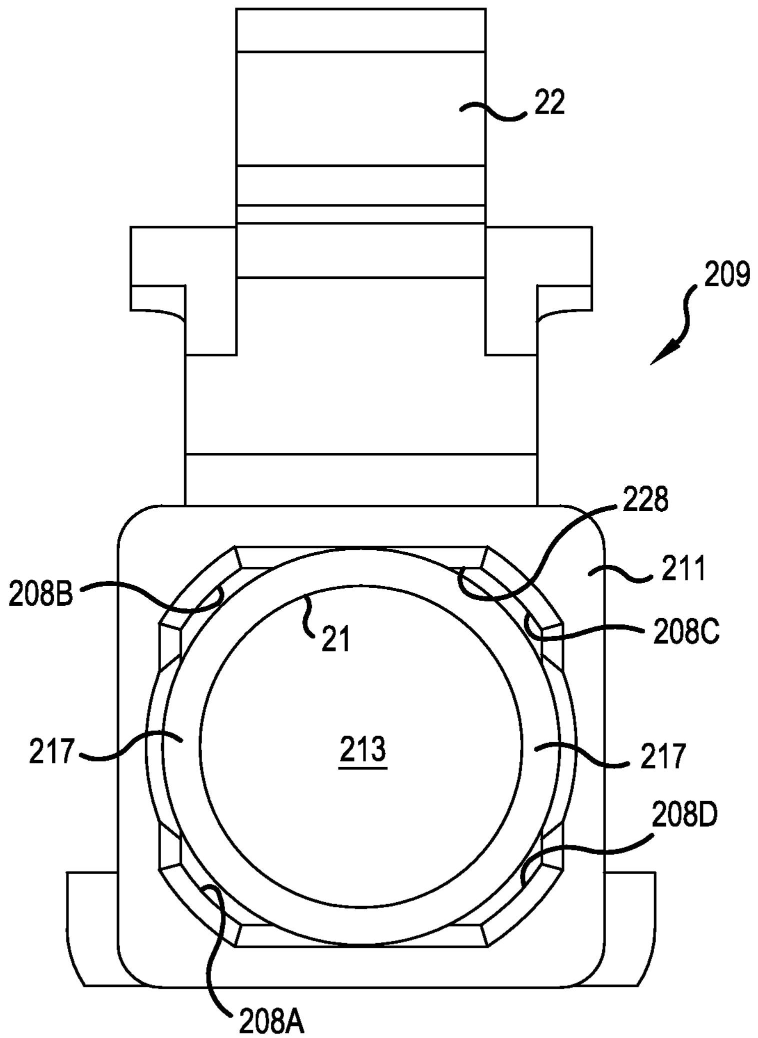
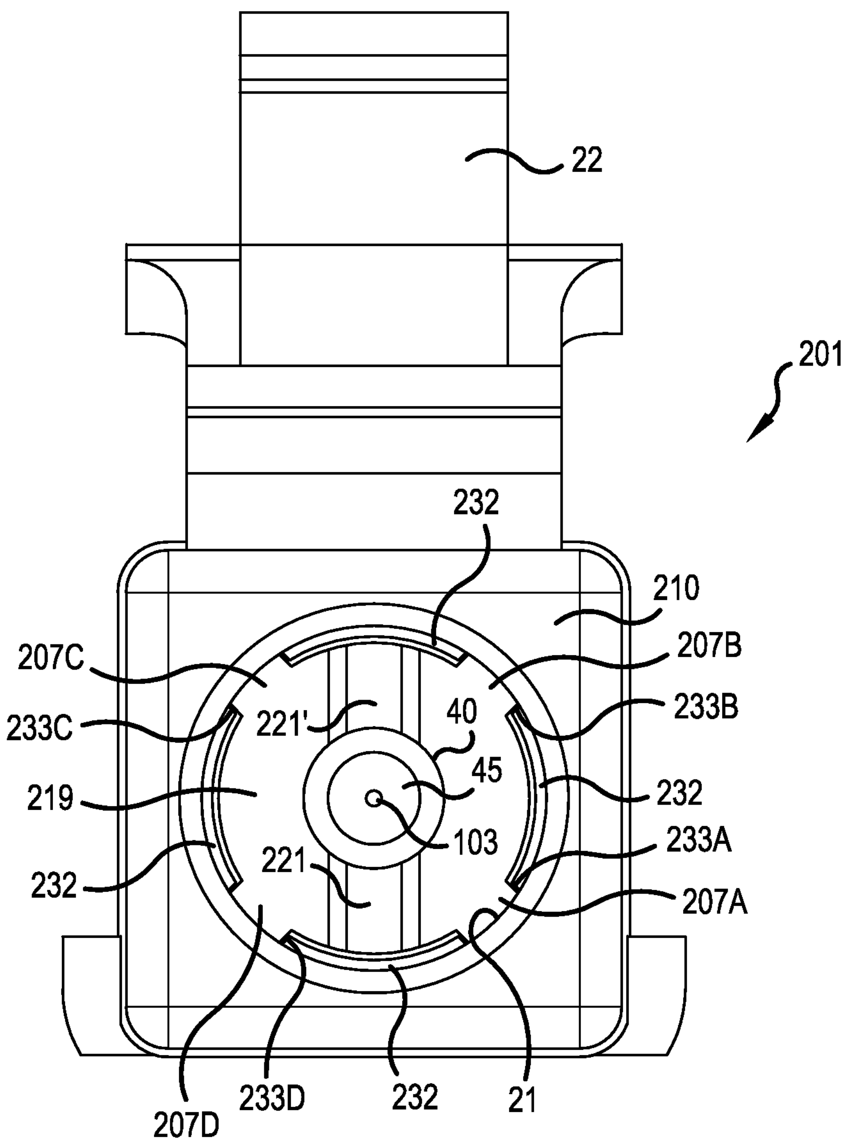


FIG.11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233D
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FIG.12

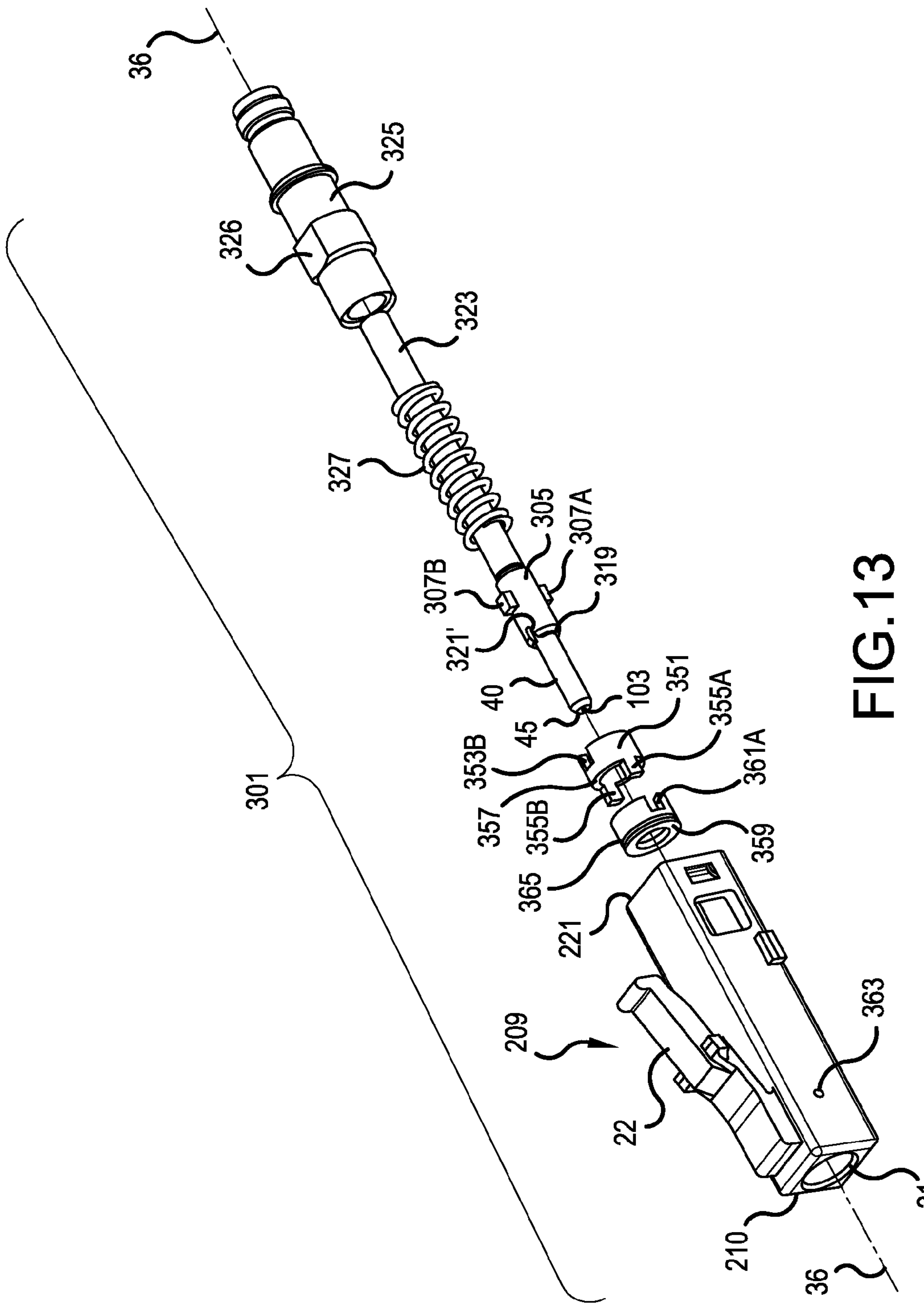
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FIG.13

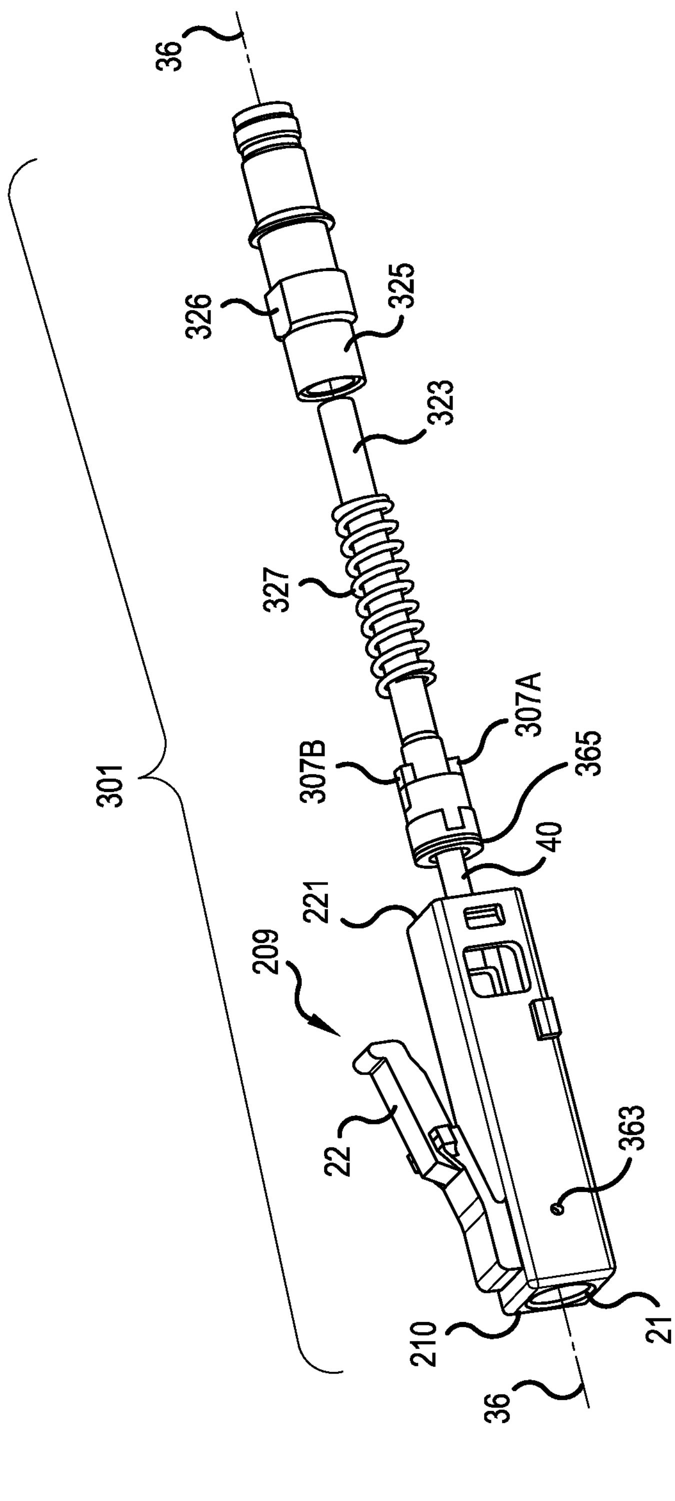


FIG.14

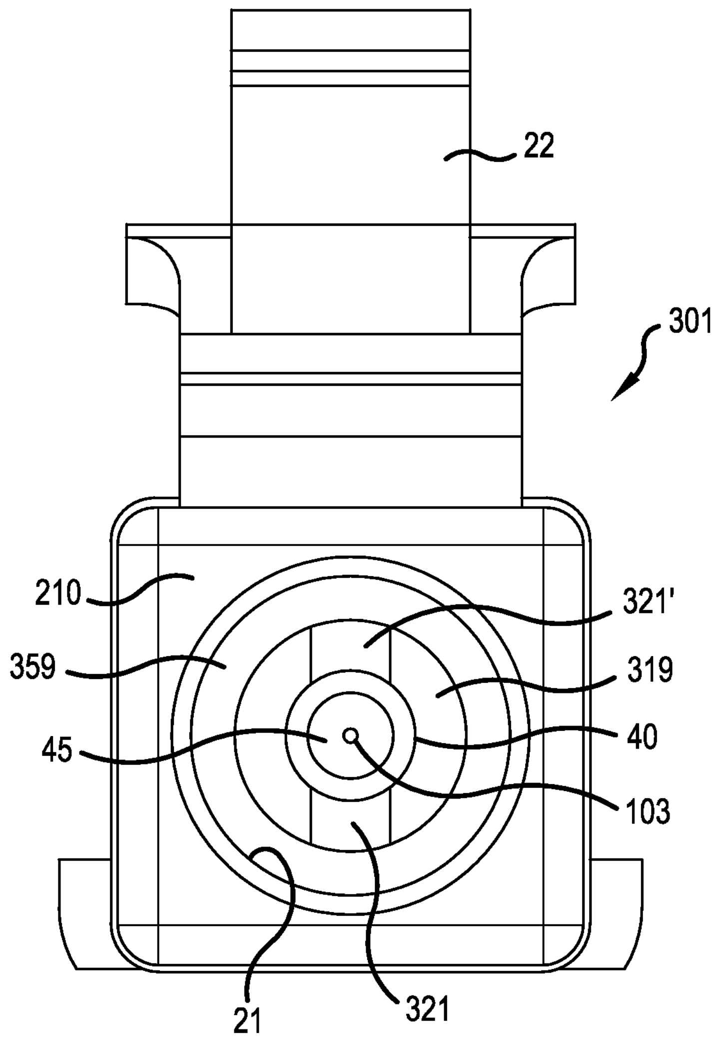
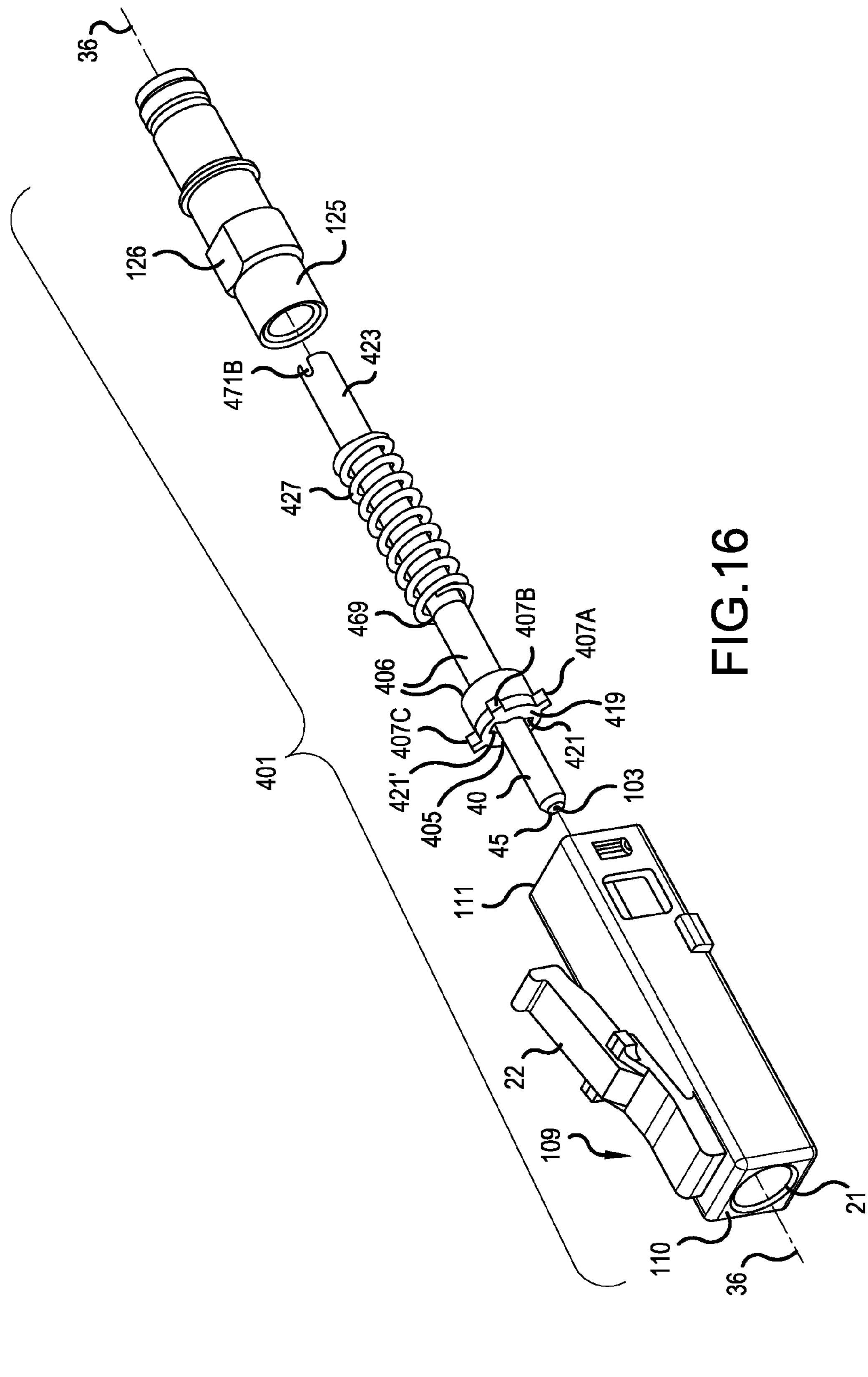


FIG.15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36

FIG.16

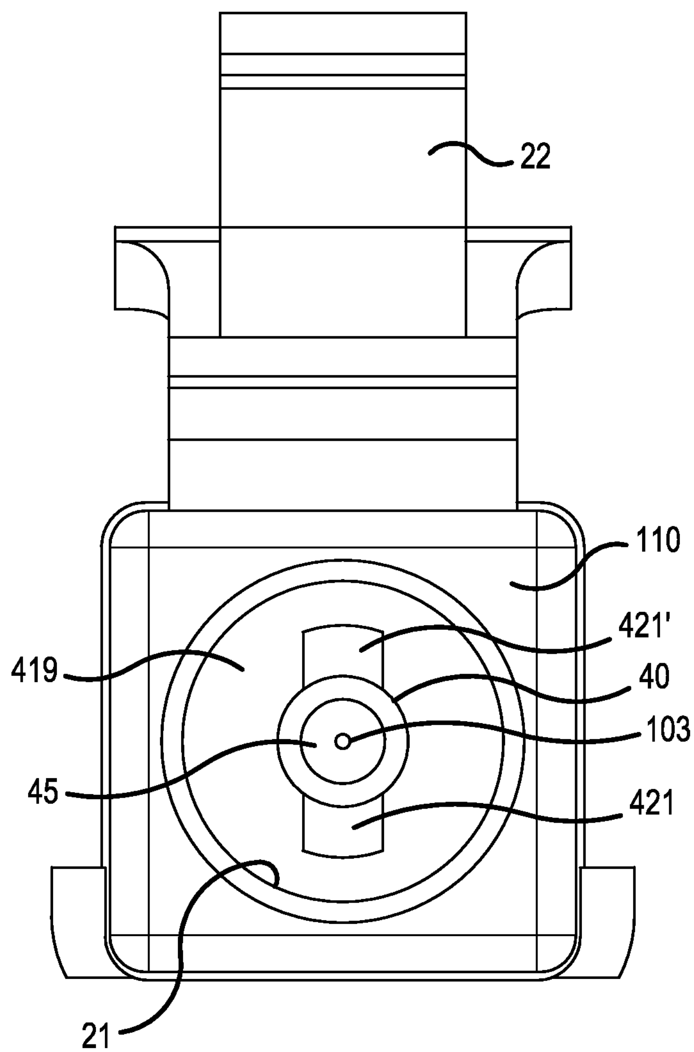

FIG.17

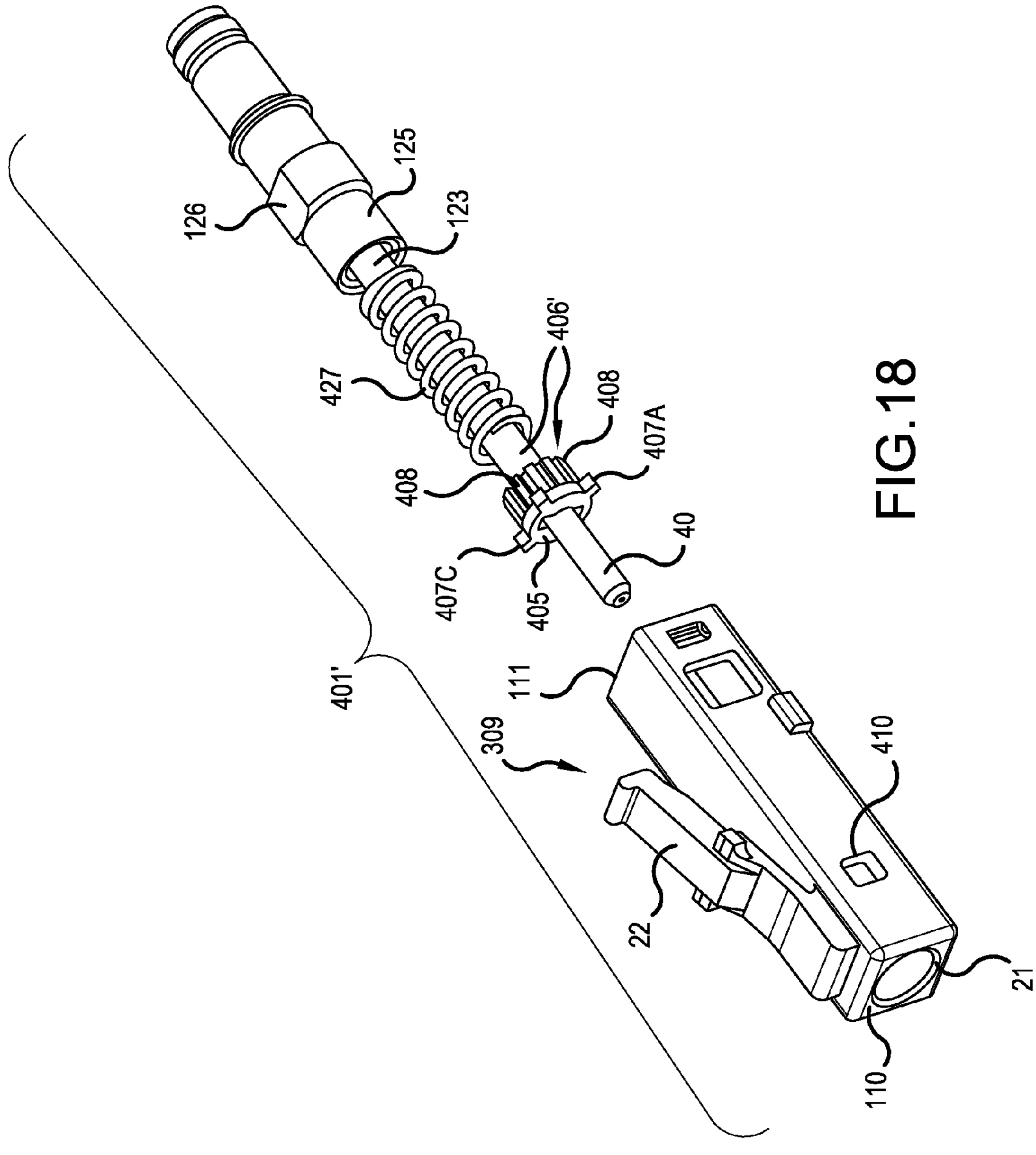
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FIG.18

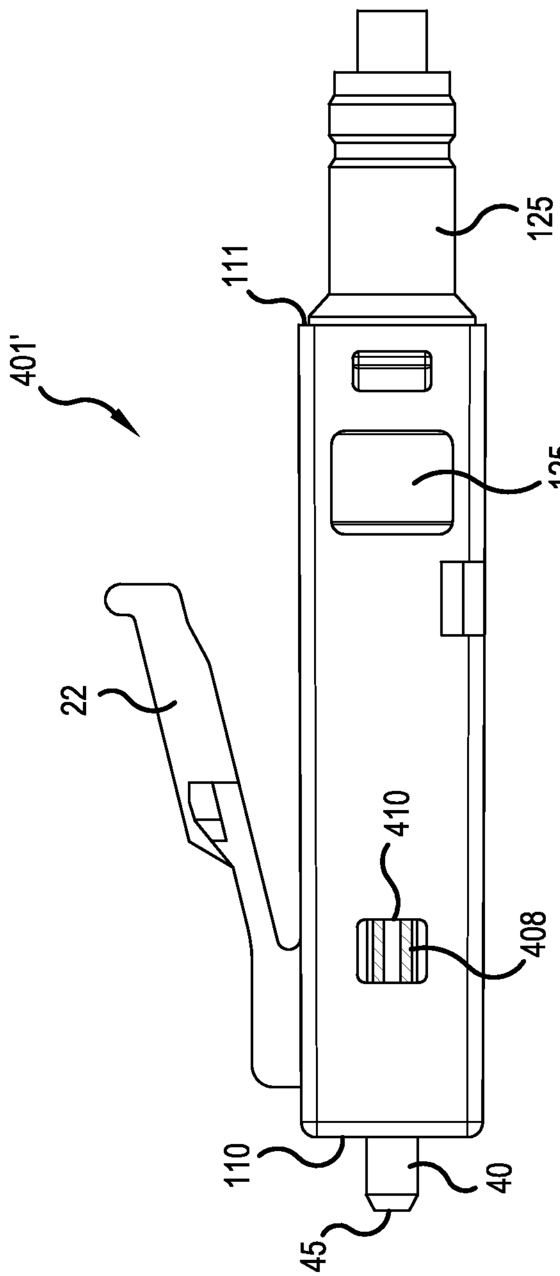

FIG.19

CONNECTOR FOR MULTIPLE CORE OPTICAL FIBER

This application claims the benefit of U.S. Provisional Application No. 61/834,796, filed Jun. 13, 2013, which is herein incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a fiber optic connector. More particularly, the present invention relates to a fiber optic connector, which enables precise alignment of the cores of a multi-core fiber end presented by the fiber optic connector relative to a feature of the connector envelope or a feature attached to the ferrule of the fiber optic connector, while enabling the ferrule to reciprocate longitudinally within the connector envelope.

2. Description of the Related Art

FIG. **1** shows an exploded view of a simplex connector, in the form of an LC connector **30**, in accordance with the prior art. The LC connector **30** comprises the following components, from left to right: plug housing **31**; ferrule subassembly **32**; spring **33**; extender **34**; and buffer boot **35**. For the purposes of the present discussion, the adjectives "front" and "lead" refer to the plug end of a connector (i.e., the left side of FIG. **1**). The adjectives "rear" and "tail" refer to the boot end of a connector (i.e., the right side of FIG. **1**). Components **31**-**35** share a common longitudinal axis **36**.

In the assembled connector **30**, the ferrule subassembly **32** with the cable end mounted thereto, "floats" along longitudinal axis **36** within an enclosure comprising plug housing **31**, extender **34**, and buffer boot **35**. Spring **33** provides spring-loading of the ferrule subassembly **32** within the enclosure, such that the ferrule subassembly **32** is biased toward the front end of plug housing **31**. Boot **35** relieves mechanical strain on an optical fiber cable **44**.

Ferrule subassembly **32** includes a ferrule **40**, a ferrule holder **41** (sometimes referred to as a ferrule barrel), and tubing **42**. The ferrule **40** has a precision hole extending down its length, along axis **36**. The hole is shaped to closely receive a bare optical fiber from a stripped end of the optical fiber cable **44**. The bare fiber is trimmed at the ferrule tip **45** and polished, resulting in an exposed fiber end face **43**. Ferrule holder **41** includes a hexagonal flange **46** and a front cone portion **49** having a pair of slots **47**, **47'** in its perimeter. The details of the slots **47**, **47'** and exposed fiber end face **43** are best seen in the close-up perspective view of the ferrule subassembly **32** shown in FIG. **2**.

When connector **30** is fully assembled, the ferrule tip **45** is accessible through an opening **21** at the front of the plug housing **31**. The plug housing **31** includes a latch arm **22** that is used to releasably attach the connector **30** into a corresponding socket or jack (not shown).

As best seen in FIG. **3**, when connector **30** is fully assembled, the hexagonal flange **46** is seated in a corresponding hexagonal cavity **23** within plug housing **31**, thereby limiting rotation of the flange/ferrule assembly **32** around axis **36**.

FIG. **4** shows a perspective view of a tuning wrench **50** that can be used to rotate the ferrule subassembly **32** around its longitudinal axis **36** in an assembled connector **30**. The ferrule subassembly **32** can be rotated in order to improve core alignment, as will be discussed in relation to FIG. **5**. As shown in FIG. **4**, the tuning wrench **50** includes a hollow shaft **51** having an opening **52** therein that fits through the plug housing opening **21** and around the ferrule **40**. Teeth **53**, **53'** engage the pair of slots **47**, **47'** in the front cone portion **49** of the ferrule holder **41**.

In use, the tuning wrench **50** pushes the ferrule subassembly **32** along its longitudinal axis **36** toward the tail end of the assembled connector **30**, such that spring **33** is compressed, and such that hexagonal flange **46** is unseated from its receiving cavity **23** in plug housing **31**. Once the hexagonal flange **46** is unseated, the ferrule subassembly **32** can then be freely rotated clockwise or counter-clockwise around its longitudinal axis **36**. Releasing the tuning wrench **50** causes the hexagonal flange **46** to be reseated in its receiving cavity **23**. It will be appreciated that the ferrule subassembly **32** can only be rotated to one of six orientations (i.e., sixty degree positional tuning) relative to the plug housing **31**, corresponding to the six possible engagement locations of the hexagonal flange **46** within the corresponding hexagonal cavity **23** of the plug housing **31**.

FIG. **5** illustrates the six potential placements **43**A-**43**F of the exposed fiber end face **43**. The reason the exposed fiber end face **43** is not always dead center is due to manufacturing tolerances in getting the fiber core **12** centered in the cladding layer **16**, and/or an off-center or canted hole extending down the length of the ferrule **40**, and/or the hole in the ferrule **40** is oversized to allow for the epoxy adhering the optical fiber into the hole, and the epoxy is not forming an even layer around the optical fiber within the hole.

Therefore, is it commonly known to view and/or detect the end face **43** of the optical fiber and use the tuning wrench **50** to select the one position, shown in bold with reference numeral **43**E, out of the six potential positions **43**A-**43**F, which best places the fiber core **12** of the exposed fiber end face **43** in the center of the opening **21** of the plug housing **31**. Alternatively the fiber core can be positioned closest to a preferred location, for example 12 o'clock, to maximize transmission between two coupled connectors. The best positioning of the end face **43**, e.g., the position which best minimizes the eccentric error, may also be determined with resort to a light measuring detector, which measures the intensity of light being received from the center of the connector end. More details concerning the correction of the eccentric error can be found in US Published Application 2002/0085815, which is herein incorporated by reference.

As can be seen in FIG. **3**, the fit between the hexagonal flange **46** and the corresponding hexagonal cavity **23** of the plug housing **31** has significant play **60**, **61**. A typical hexagon flange **46** has a width dimension of X, e.g., 2.80 mm, while a typical hexagonal cavity **23** within the plug housing **31** has a width of Y, e.g., 3.07 mm. Based upon these measurements, Applicants have evaluated the play and found that the hexagonal flange **46** may rotated up to +/−twelve degrees within the hexagonal cavity **23** of the plug housing **31**. The +/−play is represented by the doubled headed arrows **60** and **61** in FIG. **3**. Such play has been acceptable in the art, wherein the optic fiber **43** presented a single core **12** transmitting light. As one could typically select one of the potential six positions, e.g., a sixty degree optimization, and minimize the eccentric error to a level producing acceptable dB loss across a mated pair of connectors, and the +/−additional twelve degree of play did not greatly deteriorate the dB loss across the mated pair of connectors.

A current development in the fiber arts is the multi-core optical fiber **43'**. As shown in FIG. **6**, the multi-core optical fiber **43'** presents multiple cores **12***a*-**12***g* within a single cladding layer **16**. The depiction of FIG. **6** shows a center core **12***a* and six satellite cores **12***b*-**12***g*.

When a first multi-core optical fiber connector **30** mates with a second multi-core optical fiber connector **30**A, it is important that each core **12***a*-**12***g* of the first multi-core optical fiber connector **30** comes into alignment with each core **12***a*-**12***g* of the second multi-core optical fiber connector **30**A. Therefore, the play **60** and **61** depicted in FIG. **3** is not acceptable. A plus or minus twelve degree shift could allow the satellite cores **12***b*-**12***g* to be completely offset and out of communication when a first multi-core optical fiber connector **30** is mated to a second multi-core optical fiber connector **30**A via a pass through adapter.

To address this concern, the prior art of US Published Application 2011/0229085, which is herein incorporated by reference, has reduced the allowable tolerances between the hexagonal flange **46** of the ferrule holder **41** and the hexagonal cavity **23** of the plug housing **31**. In US Published Application 2011/0229085, "a tightly toleranced internal hexagonal cavity" is employed, as it is important that the shape geometry employed on the collar of the ferrule holder "match" the shape geometry employed in the internal plug housing. Excessive play, e.g., +/−twelve degrees, would not be acceptable.

In US Published Application 2011/0229085, the external geometry of the ferrule holder, e.g., the hexagonal flange **46**, is tightly seated without play into the internal geometry of the plug housing, e.g., the hexagonal cavity **23**, relatively rotatable parts of the connector which could effect the angular placement of the satellite cores **12***b*-**12***g* are preferably locked down in place with epoxy.

SUMMARY OF THE INVENTION

The Applicant has appreciated drawbacks in the multi-core fiber optic connectors of the prior art. It is an object of the present invention to address one or more of the drawbacks and other perceived needs in the art.

It is appreciated that precision molding of the internal cavity of the plug housing is difficult and increases the costs. Plug housings with out-of-tolerance internal cavities would need to be recycled. Further, the plastic portions of the housing can be subject to abrasion and may over time expand to develop play in the nesting between the external geometry of the ferrule holder and the internal geometry of the plug housing, which could lead to degraded communication performance in one or more cores. Also, the entire plug housing may slightly rotate about its central axis within a port of an adapter because of a clearance fit between the plug's housing and the walls of the port. Also, the mating force between ferrules is produced by a spring and relies on a clearance fit between the ferrule holder and connector housing. An interference fit or bonded fit between the ferrule holder and housing can increase or decrease the force between mated connectors, especially when manufacturing tolerances along the axis of the connector system vary.

It is an object of the present invention to provide a low cost dependable fiber optic plug, suitable for multi-core optical fibers, whereby the satellite cores of a multi-core fiber are held in a proper angular position by a ferrule so as to attain suitable alignment with the satellite cores of a mating connector, while permitting the ferrule to move longitudinally relative to the connector housing, so that a spring may control a mating force to an abutting ferrule of a mating connector.

These and other objects are accomplished by new plug or connector structures. The connector structures may hold the satellite fibers in a more precise alignment than achievable in the prior art connector structures, while also permitting the ferrule to move longitudinally relative to the connector housing. Also, the new connector structures may operate in conjunction with a tabbed sleeve, as described in the Applicant's co-pending U.S. patent application Ser. No. 14/161,792, filed Jan. 23, 2014, which is incorporated herein by reference.

Further scope of applicability of the present invention will become apparent from the detailed description given hereinafter. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus, are not limits of the present invention, and wherein:

FIG. **1** is an exploded, perspective view of an LC connector for an optical fiber, in accordance with the prior art;

FIG. **2** is a close-up, perspective view of a ferrule subassembly in FIG. **1**;

FIG. **3** is a diagram depicting play in the fitting of a hexagonal flange of a ferrule holder within a hexagonal cavity of a plug housing, in accordance with the prior art;

FIG. **4** is a perspective view of a tuning wrench, in accordance with the prior art;

FIG. **5** is a diagram depicting six potential locations of a fiber end presented by a fiber optical connector due to an eccentric error in the fiber placement, in accordance with the prior art;

FIG. **6** is an end view of a multi-core optical fiber, in accordance with the prior art;

FIG. **7** is an exploded, perspective view of a first connector for an optical fiber, in accordance with a first embodiment of the present invention;

FIG. **8** is a rear view of an empty connector housing depicted in FIG. **7**;

FIG. **9** is a front view of the connector housing of FIGS. **7** and **8** with a ferrule assembly of FIG. **7** installed in the connector housing;

FIG. **10** is an exploded, perspective view of a second connector for an optical fiber, in accordance with a second embodiment of the present invention;

FIG. **11** is a rear view of an empty connector housing depicted in FIG. **10**;

FIG. **12** is a front view of the connector housing of FIGS. **10** and **11** with a ferrule assembly of FIG. **10** installed in the connector housing;

FIG. **13** is an exploded, perspective view of a third connector for an optical fiber, in accordance with a third embodiment of the present invention;

FIG. **14** is a perspective view of a third connector of FIG. **13** showing several parts assembled;

FIG. **15** is a front view of a connector housing of FIGS. **13** and **14** with a ferrule assembly of FIGS. **13** and **14** installed in the connector housing;

FIG. **16** is an exploded, perspective view of a fourth connector for an optical fiber, in accordance with a fourth embodiment of the present invention;

FIG. **17** is a front view of the connector housing of FIG. **16** with a ferrule assembly of FIG. **16** installed in the connector housing;

FIG. **18** is an exploded, perspective view of the fourth connector for an optical fiber, having an alternative ferrule adjustment mechanism; and

FIG. **19** is a side view of the connector of FIG. **18**.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

The present invention now is described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

Like numbers refer to like elements throughout. In the figures, the thickness of certain lines, layers, components, elements or features may be exaggerated for clarity. Broken lines illustrate optional features or operations unless specified otherwise.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the specification and relevant art and should not be interpreted in an idealized or overly formal sense unless expressly so defined herein. Well-known functions or constructions may not be described in detail for brevity and/or clarity.

As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. As used herein, phrases such as "between X and Y" and "between about X and Y" should be interpreted to include X and Y. As used herein, phrases such as "between about X and Y" mean "between about X and about Y." As used herein, phrases such as "from about X to Y" mean "from about X to about Y."

It will be understood that when an element is referred to as being "on", "attached" to, "connected" to, "coupled" with, "contacting", etc., another element, it can be directly on, attached to, connected to, coupled with or contacting the other element or intervening elements may also be present. In contrast, when an element is referred to as being, for example, "directly on", "directly attached" to, "directly connected" to, "directly coupled" with or "directly contacting" another element, there are no intervening elements present. It will also be appreciated by those of skill in the art that references to a structure or feature that is disposed "adjacent" another feature may have portions that overlap or underlie the adjacent feature.

Spatially relative terms, such as "under", "below", "lower", "over", "upper", "lateral", "left", "right" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is inverted, elements described as "under" or "beneath" other elements or features would then be oriented "over" the other elements or features. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the descriptors of relative spatial relationships used herein interpreted accordingly.

Fiber optic jumpers, patch cords, trunk cables, fanouts and other cable configurations provide optical connectivity in numerous spaces including LANs, WANs, Datacenters, vehicles, aircraft and ships. Historically, all have used one or more single core optical fibers. New optical fibers with multiple optical cores are in development. The multiple optical cores are often arranged in polar arrays with one central core surrounded by multiple satellite cores, all at the same radial distance from the central core. Other core arrangements, including polar arrays with cores located on multiple radii and hexagonal arrays are less common. Connectors that control the angular position and angular rotation of the multiple core fibers are needed to form low cost, low loss connections.

In most existing single fiber connectors, optical fiber is bonded into a ferrule which floats under spring force within a connector housing. The angular fiber/ferrule rotation has not been tightly controlled in current designs. Many connectors allow +/−12 degrees of rotation. A multi-core fiber (MCF) with 33 micron diameter satellite cores located on a 58 micron radius would align only 88% of the satellite core area if each fiber were rotated 3 degrees in opposite directions. A maximum angular alignment of +/−0.75 degrees would need to be maintained to adequately align single mode (SM) MCF with eight micron diameter satellites on a 34 micron radius. Connectors that tightly control angular fiber rotation are needed in the art.

The following connectors are designed to tightly control the angular rotation of MCF. Each connector design has unique characteristics. Some designs are simple and require the fiber to be clocked before the fiber is bonded to the ferrule. Others connector designs contain more pieces that allow the fiber to be clocked after the fiber has been bonded to the ferrule. Still other connector designs allow the fiber to be clocked after it is bonded to the ferrule and also allow the connector to couple to a tabbed sleeve for additional alignment control. The unique features found in the separate designs can be combined in different ways to form additional connector designs, which are considered part of the scope of this patent.

FIG. **7** is an exploded, perspective view of a first multi-core fiber (MCF) connector **101**, in accordance with a first embodiment of the present invention. Structures, which are the same or similar to the prior art depicted in FIGS. **1-3** have been labeled by a same reference numeral. The first MCF fiber connector **101** includes a ferrule **40**, which is cylindrical in shape. A multi-core fiber **103** is secured within a central bore of the ferrule **40**, e.g., by epoxy. A ferrule barrel **105** surrounds at least a portion of the ferrule **40**, and may be attached to the ferrule **40** by epoxy or by a press fit.

The ferrule barrel **105** includes at least one spline **107** extending away from an outer peripheral surface of the ferrule barrel **105**. In a preferred embodiment, the at least one spline **107** includes four splines **107**A, **107**B, **107**C and **107**D, each extending away from the outer peripheral surface of the ferrule barrel **105**, and the four splines **107**A, **107**B, **107**C and **107**D are equally spaced around the peripheral surface of the ferrule barrel **105** at intervals of ninety degrees.

As best seen in FIG. **8**, a connector housing **109** has a rear face **111** with an opening to an inner cavity **113**. FIG. **8** depicts the inner cavity **113** as empty, and leading up to the opening **21** in a front face **110** of the connector housing **109**. The inner cavity **113** is sized to accept the ferrule barrel **105**, which when fully inserted abuts to a ridge or ledge **117** located at some depth within the cavity **113** (but not necessarily directly behind the front face **110** of the connector housing **109**), so that the ferrule barrel **105** cannot pass entirely through the cavity **113** and out the opening **22**.

The inner cavity **113** includes at least one notch **115** on its inner periphery, such as four notches **115**A, **115**B, **115**C and **115**D equally spaced ninety degrees apart around the inner periphery of the cavity **113**. The notches **115**A, **115**B, **115**C and **115**D are sized to receive the splines **107**A, **107**B, **107**C and **107**D and to permit the splines **107**A, **107**B, **107**C and **107**D to move within the notches **115**A, **115**B, **115**C and **115**D in a first direction which is substantially parallel to an extension direction of the ferrule **40**, e.g., parallel to the axis **36**. In a preferred embodiment, a width of each notch **115** is not more than 0.003 inches greater than a width of each spline **107**, so as to permit longitudinal, reciprocal movement of the ferrule barrel **105** relative to the connector housing **109** along the axis **36** passing through the center of ferrule **40**, and so as to limit rotation of the ferrule barrel **105** around the axis **36** to less than +/−2.3 degrees relative to the connector housing **109**, translating to +/−2.2 um translation at the satellite cores of the MCF **103**.

In a preferred embodiment, a front face **119** of the ferrule barrel **105** lies in a plane, which is substantially perpendicular to the axis **36** or extension direction of the ferrule **40**. The front face **119** includes first and second recessed portions **121** and **121'** to receive a tab of a sleeve in an adapter. In a preferred embodiment, the cores of the multi-core fiber **103** are clocked relative to an edge of the recessed portions **121** and **121'** prior to the multi-core fiber **103** being bonded within the ferrule **40**. Details concerning clocking the cores of the multi-core fiber **103** to an edge of one of the recessed portions **121** or **121'**, and details concerning the tabbed sleeve of an adapter using the recessed portions **121** and **121'** for satellite core alignment between mating connectors within the adapter can be found in Applicant's co-pending U.S. application Ser. No. 14/161,792, filed Jan. 23, 2014, which is herein incorporated by reference.

In a preferred embodiment, the first MCF fiber connector **101** further includes a tube **123** surrounding the multi-core fiber **103** to the rear of the ferrule barrel **105**. An extender **125** loosely surrounds the tube **123**. A spring **127** surrounds the tube **123** and resides between a backside of the ferrule barrel **105** and a forward face of the extender **125**. The spring **127** biases the ferrule barrel **105** away from the extender **125**.

The extender **125** has an indexing feature **126** to align it with a mating feature **128** on the backside **111** of the connector housing **109**. The front of the extender **125** gets inserted into the cavity **113** and is adhered to a portion of the inner cavity **113** of the connector housing **109**. Therefore, the spring **127** tends to push the front face **119** of the ferrule barrel **105** into contact with the ledge **117**. The spring **127** can be compressed when the ferrule tip **45** is contacted by another ferrule tip of a mating connector, thereby permitting the front face **119** of the ferrule barrel **105** to leave the ledge **117**.

FIG. **9** is a front view of the connector housing **109** and best illustrates the front face **119** of the ferrule barrel **105** when fully seated into the cavity **113**, i.e., in abutment with the ledge **117** within the cavity **113**. The recessed portions **121** and **121'** are accessible through the opening **21** in the front face **110** of the connector housing **109**, and can be engaged by a tab of a tabbed alignment sleeve within an adapter, as noted above, to provide precise rotational alignment in the mating of satellite cores while still enabling the ferrule **40** to be pressed rearwardly into the connector housing **109**.

Although FIGS. **7-9** have depicted the connector housing **109** as defining an LC type connector envelope, the connector housing **109** may take other forms like SC or ST type connector housings. This substitution of connector housing features is applicable to all embodiments of the present application.

FIG. **10** is an exploded, perspective view of a second MCF connector **201**, in accordance with a second embodiment of the present invention. Structures, which are the same or similar to the prior art or earlier embodiments, have been labeled by a same reference numeral. The second MCF fiber connector **201** includes a ferrule **40**, which is cylindrical in shape. A multi-core fiber **103** is secured within a central bore of the ferrule **40**, e.g., by epoxy. A ferrule barrel **205** surrounds at least a portion of the ferrule **40**, and may be attached to the ferrule **40** by epoxy or by a press fit.

The ferrule barrel **205** includes at least one spline **207** extending away from an outer peripheral surface of the ferrule barrel **205**. In a preferred embodiment, the at least one spline **207** includes four splines **207**A, **207**B, **207**C and **207**D, each extending away from the outer peripheral surface of the ferrule barrel **205**, and the four splines **207**A, **207**B, **207**C and **207**D are equally spaced around the peripheral surface of the ferrule barrel **205** at intervals of ninety degrees.

A strength member **231** surrounds the multi-core fiber **103** to a rear of the ferrule barrel **205**. The strength member **231** is a generally tubular member and includes at least one notch **233** for receiving the at least one spline **207**. For example, the strength member **231** may include four notches **233**A, **233**B, **233**C and **233**D, equally spaced, ninety degrees apart and extending through the outer peripheral surface of the strength member **231** up to a front face **232** of the strength member **231**.

The notches **233**A, **233**B, **233**C and **233**D are sized to receive the splines **207**A, **207**B, **207**C and **207**D and to permit the splines **207**A, **207**B, **207**C and **207**D to move within the notches **233**A, **233**B, **233**C and **233**D in a first direction, which is substantially parallel to an extension direction of the ferrule **40**, e.g., parallel to the axis **36**. In a preferred embodiment, a width of each notch **233** is not more than 0.002 inches greater than a width of each spline **207**, so as to permit reciprocal longitudinal movement of the ferrule barrel **205** along the axis **36** passing through the center of ferrule **40** relative to the strength member **231**, and so as to limit rotation of the ferrule barrel **205** around the axis **36**, translating to no more than +/−1.25 um translation at satellite cores.

In a preferred embodiment, a front face **219** of the ferrule barrel **205** lies in a plane, which is substantially perpendicular to the axis **36** or extension direction of the ferrule **40**. The front face **219** includes first and second recessed portions **221** and **221'** to receive a tab of a sleeve in an adapter. In a preferred embodiment, the cores of the multi-core fiber **103** are clocked relative to an edge of the recessed portions **221** and **221'** prior to the multi-core fiber **103** being bonded within the ferrule **40**. Again, details concerning clocking the cores of the multi-core fiber **103** to an edge of one of the recessed portions **221** or **221'**, and details concerning the sleeve of an adapter using the recessed portions **221** and **221'** for satellite core alignment between mating connectors within the adapter can be found in Applicant's co-pending U.S. application Ser. No. 14/161,792.

As best seen in FIG. **11**, a connector housing **209** has a rear face **211** with an opening to an inner cavity **213**. FIG. **11** depicts the inner cavity **213** as empty, and leading up to the opening **21** in a front face **210** of the connector housing **209**. The inner cavity **213** is sized to accept the strength member **231** with the ferrule barrel **205** therein. When the strength member **231** with the ferrule barrel **205** are fully inserted, the front face **232** of the strength member **231** and the front face **219** of the ferrule barrel **205** abut to a ridge or ledge **217** located at some depth within the cavity **213**, so that the ferrule barrel **205** and strength member **231** cannot pass entirely through the cavity **213** and out the opening **22**. The cavity **213** may optionally include indentations **208**A, **208**B, **208**C and **208**D around its inner peripheral surface, which are sized to accommodate any portion of the splines **207**A, **207**B, **207**C and **207**D, which extend outwardly of the notches **233**A, **233**B, **233**C and **233**D in the strength member **231**. The indentations **208**A, **208**B, **208**C and **208**D do not provide guidance to the splines **207**A, **207**B, **207**C and **207**D, only clearance to permit movement inside the cavity **213**.

In a preferred embodiment, the second MCF fiber connector **201** further includes a tube **223** surrounding the multi-core fiber **103** to the rear of the ferrule barrel **205**. The tube **223** passes loosely through the strength member **231**. An extender **225** surrounds the strength member **231** and is attached to the strength member **231**, e.g., by an epoxy. Optionally, a hole **240** is provided in the extender **225** and leads to the interfacing surfaces between extender **225** and the strength member **231** to aid in the epoxy application. A spring **227** surrounds the tube **223** and resides between a backside of the ferrule barrel **205** and a ledge **234** within the strength member **231**. The spring **227** biases the ferrule barrel **205** away from the strength member **231**.

The extender **225** has an indexing feature **226** to align it with a mating feature **228** on the backside **211** of the connector housing **209**. The front of the extender **225** gets inserted into the cavity **213** and pushed into the cavity **213** until the front face **232** of the strength member **231** abuts the ledge **217**, then the extender **225** is attached to a portion of the inner cavity **213** of the connector housing **209**, e.g., by epoxy, or alternatively the extender **225** is snapped into the connector housing **209** by protruding into openings in the sides of the housing, as illustrated in FIG. **19**. Therefore, the spring **227** tends to push the front face **219** of the ferrule barrel **205** into contact with the ledge **217**. The spring **227** can be compressed when the ferrule tip **45** is contacted by another ferrule tip of a mating connector, thereby permitting the front face **219** of the ferrule barrel **205** to leave the ledge **217**.

FIG. **12** is a front view of the connector housing **209** and best illustrates the front face **219** of the ferrule barrel **205** when fully seated into the cavity **213**, i.e., in abutment with the ledge **217** within the cavity **213**. The recessed portions **221** and **221'** are accessible through the opening **21** in the front face **210** of the connector housing **209**, and can be engaged by a tab of a tabbed alignment sleeve within an adapter, as noted above, to provide precise rotational alignment in the mating of satellite cores while still enabling the ferrule **40** to be pressed rearwardly into the connector housing **209**.

FIG. **13** is an exploded, perspective view of a third multi-core fiber (MCF) connector **301**, in accordance with a third embodiment of the present invention. Structures, which are the same or similar to the prior art or earlier embodiments, have been labeled by a same reference numeral. The third MCF fiber connector **301** includes a ferrule **40**, which is cylindrical in shape. A multi-core fiber **103** is secured within a central bore of the ferrule **40**, e.g., by epoxy. A ferrule barrel **305** surrounds at least a portion of the ferrule **40**, and may be attached to the ferrule **40** by epoxy or by a press fit.

The ferrule barrel **305** includes at least one spline **307** extending away from an outer peripheral surface of the ferrule barrel **305**. In a preferred embodiment, the at least one spline **307** includes first and second splines **307**A and **307**B, each extending away from the outer peripheral surface of the ferrule barrel **305**, and the first and second splines **307**A and **307**B are equally spaced around the peripheral surface of the ferrule barrel **305**, i.e., one hundred and eighty degrees apart.

A first collar **351** surrounds the ferrule **40** on a forward or first side of said ferrule barrel **305**. The first collar **351** includes first and second notches **353**A and **353**B to receive the first and second splines **307**A and **307**B. The first and second notches **353**A and **353**B are located one hundred and eighty degrees apart (with the first notch **353**A being hidden from view in FIGS. **13** and **14**). The first and second notches **353**A and **353**B allow the first and second splines **307**A and **307**B to slide therein. The first collar **351** includes first and second tabs **355**A and **355**B protruding away from a forward surface **357** of the first collar **351**. In a preferred embodiment, the first and second tabs **355**A and **355**B are offset by approximately ninety degrees relative to the first and second notches **353**A and **353**B of the first collar **351**.

A second collar **359** surrounds the ferrule **40**. The second collar **359** includes third and fourth notches **361**A and **361**B to receive the first and second tabs **355**A and **355**B and allow the first and second tabs **355**A and **355**B to slide therein.

In a preferred embodiment, a front face **319** of the ferrule barrel **305** lies in a plane, which his substantially perpendicular to the axis **36** or extension direction of the ferrule **40**. The front face **319** includes first and second recessed portions **321** and **321'** to receive a tab of a sleeve in an adapter. In a preferred embodiment, the cores of the multi-core fiber **103** are clocked relative to an edge of the recessed portions **321** and **321'** before the MCF **103** is bonded into the ferrule **40**.

In a preferred embodiment, the third MCF fiber connector **301** further includes a tube **323** surrounding the multi-core fiber **103** to the rear of the ferrule barrel **305**. An extender **325** loosely surrounds the tube **323**. A spring **327** surrounds the tube **323** and resides between a backside of the ferrule barrel **305** and a forward face of the extender **325**. The spring **327** biases said ferrule barrel **305** away from the extender **325**.

The connector housing **209** may be formed the same as the connector housing **209** for the second embodiment. In other words, FIG. **11** depicts the rear face **211** of the connector housing **209** for the third embodiment.

During assembly of the third MCF optic connector **301**, the second collar **359** gets inserted into the cavity **213** and is adhered to a portion of the inner cavity **213** of the connector housing **209**. The connector housing may include a hole **363** in a sidewall to accept epoxy. And the second collar **359** may include a track **365** aligned to the hole **363** when the second collar **359** is in abutment with the ledge **217** within the cavity **213**. Next, the ferrule assembly, with the first collar **351** encircling the ferrule barrel **305** with the splines **307**A and **307**B within the notches **353**A and **353**B, is inserted into the cavity **213**.

As best seen in FIG. **15**, the ferrule **40** passes out of the opening **21** in the front face **210** of the connector housing **209**. The first and second tabs **355**A and **355**B are inserted into the third and fourth notches **361**A and **361**B of the second collar **359**. Next, the extender **325** is pressed into the cavity, against a biasing force supplied by the spring **327**. The extender **325** has an indexing feature **326** to align it with the mating feature **228** on the rear face **211** of the connector housing **209**. The front of the extender **325** gets inserted into the cavity **213** and is attached to a portion of the inner cavity **213** of the connector housing **209**, e.g., by epoxy, or alternatively the extender **325** is snapped into the connector housing **209** by protruding into openings in the sides of the housing, as illustrated in FIG. **19**. Therefore, the spring **327** tends to push the first and second splines **307**A and **307**B fully into the first and second notches **353**A and **353**B and simultaneously tends to press the first and second tabs **355**A and **355**B into the third and fourth notches **361**A and **361**B.

The spring **327** can be compressed when the ferrule tip **45** is contacted by another ferrule tip of a mating connector, thereby permitting the front face **319** of the ferrule barrel **305** to move rearwardly. During rearward movement of the ferrule barrel **305**, either the first and second splines **307**A and **307**B move in the first and second notches **353**A and **353**B, or the first and second tabs **355**A and **355**B move in the third and fourth notches **361**A and **361**B, or both actions occur.

FIG. **15** is a front view of the connector housing **209** and best illustrates the front face **319** of the ferrule barrel **305** when fully seated into the cavity **213**, i.e., with all splines **307**, tabs **355** and notches **353**, **361** in abutment. The recessed portions **321** and **321'** are accessible through the opening **21** in the front face **210** of the connector housing **209**, and can be engaged by a tab of a tabbed alignment sleeve within an adapter, as noted above, to provide precise rotational alignment in the mating of satellite cores while still enabling the ferrule **40** to be pressed rearwardly into the connector housing **209**.

In a preferred embodiment, the ferrule barrel **305**, the first collar **351** and the second collar **359** may all formed of metal. Forming these component parts of metal allows the splines **307**, notches **353**, **361** and tabs **355** to all be machined to a close tolerance, a much closer tolerance than obtainable via plastic molded structures. The metal pieces will also maintain a more consistent tolerance over time, as compared to plastic pieces which wear and derogate more over time. In one embodiment, the tolerance fit between the tabs **355** and notches **361** of the first and second collars **351**, **359** may be on the order of 0.5 thousandths of an inch, and the tolerances fit between the splines **307** of the ferrule barrel **305** and notches **353** of the first collar **351** may be on the order to 0.5 thousandths of an inch. In one embodiment, the notches **535**, **361**, splines **307** and tabs **355** permit the ferrule **40** to be moved into the connector body (in the direction of extension of the ferrule, along axis **36**) a distance of about 2 mm, as the spring **327** is compressed, while limiting rotation of the ferrule **40** around the axis **36** to less than +/−1.8 degrees relative to the connector housing **209**, translating to +/−1.85 um translation at the satellite cores of the MCF **103**.

FIG. **16** is an exploded, perspective view of a fourth MCF connector **401**, in accordance with a fourth embodiment of the present invention. Structures, which are the same or similar to the prior art or earlier embodiments, have been labeled by a same reference numeral. The fourth MCF fiber connector **401** includes a ferrule **40**, which is cylindrical in shape. A multi-core fiber **103** is secured within a central bore of the ferrule **40**, e.g., by epoxy. A first ferrule barrel **405** surrounds at least a portion of the ferrule **40**.

The first ferrule barrel **405** includes at least one spline **407** extending away from an outer peripheral surface of the first ferrule barrel **405**. In a preferred embodiment, the at least one spline **407** includes four splines **407**A, **407**B, **407**C and **407**D, each extending away from the outer peripheral surface of the ferrule barrel **405**, and the four splines **407**A, **407**B, **407**C and **407**D are equally spaced around the peripheral surface of the first ferrule barrel **405** at intervals of ninety degrees.

The connector housing **109** may be formed the same as the connector housing **109** for the first embodiment depicted in FIG. **8**. The connector housing **109** has a rear face **111** with an opening to an inner cavity **113**. FIG. **8** depicts the inner cavity **113** as empty, and leading up to the opening **21** in a front face **110** of the connector housing **109**. The inner cavity **113** is sized to accept the first ferrule barrel **405**, which when fully inserted abuts to a ridge or ledge **117** located within the cavity **113**, so that the ferrule barrel **405** cannot pass entirely through the cavity **113** and out the opening **22**.

The inner cavity **113** includes at least one notch **115** on its inner periphery, such as four notches **115**A, **115**B, **115**C and **115**D equally spaced ninety degrees apart around the inner periphery of the cavity **113**. The notches **115**A, **115**B, **115**C and **115**D are sized to receive the splines **407**A, **407**B, **407**C and **407**D and to permit the splines **407**A, **407**B, **407**C and **407**D to move within the notches **115**A, **115**B, **115**C and **115**D in a first direction which is substantially parallel to an extension direction of the ferrule **40**, e.g., parallel to the axis **36**. In a preferred embodiment, a width of each notch **115** is not more than 0.003 inches greater than a width of each spline **407**, so as to permit reciprocal longitudinal movement of the first ferrule barrel **405** relative to the connector housing **109** along the axis **36** passing through the center of ferrule **40**, and so as to limit rotation of the first ferrule barrel **405** around the axis **36** to less than +/−2.3 degrees relative to the connector housing **109**, translating to +/−2.2 um translation at the satellite cores of the MCF **103**.

In a preferred embodiment, a front face **419** of the first ferrule barrel **405** lies in a plane, which his substantially perpendicular to the axis **36** or extension direction of the ferrule **40**. The front face **419** includes first and second recessed portions **421** and **421'** to receive a tab of a sleeve in an adapter. In a preferred embodiment, the cores of the multi-core fiber **103** are clocked relative to an edge of the recessed portions **421** and **421'** prior to bonding the MCF **103** in the ferrule **40**.

The first ferrule barrel **495** is pressed fitted onto a first portion of the ferrule **40**, such that the ferrule **40** can turn within the first ferrule barrel **405** once a first frictional coefficient existing between the ferrule **40** and the first ferrule barrel **405** is overcome. A second ferrule barrel **406** surrounds at least a second portion of the ferrule **40**, wherein rotation of the second ferrule barrel **406** causes the ferrule **40** to rotate within the first ferrule barrel **405**. The second ferrule barrel **406** is not connected to the first ferrule barrel **405**.

In a preferred embodiment, the second ferrule barrel **406** is pressed fitted onto the second portion of the ferrule **40**, and a second frictional coefficient exists between the ferrule **40** and the second ferrule barrel **406**, and the second frictional coefficient is greater than the first frictional coefficient, e.g., on the order of twice as much friction. One manner to achieve the higher second coefficient of friction is to construct the second ferrule barrel **406** to have more surface contact with the ferrule **40**. In other words, the second portion of the ferrule **40** is greater in area than the first portion of the ferrule **40**. In an alternative embodiment, the second ferrule barrel **406** is adhered to the ferrule **40**.

A tube **423** surrounds the multi-core fiber **103** to the rear of the second ferrule barrel **406**. The tube **423** is attached to the second ferrule barrel **406** along a contact area **469**. The tube **423** includes features (e.g., two notches **471**A and **471**B) for engagement by a tool to rotate the tube **423**.

An extender **125** loosely surrounds the tube **423**. A spring **427** surrounds the tube **423** and resides between a backside of the second ferrule barrel **406** and a forward face of the extender **125**. The spring **427** biases the second ferrule barrel **406** away from the extender **125**.

The extender **125** has an indexing feature **126** to align it with the mating feature **128** on the backside **111** of the connector housing **109**. The front of the extender **125** gets inserted into the cavity **113** and is attached to a portion of the inner cavity **113** of the connector housing **109** by epoxy or by snapping the extender **125** into the connector housing **109** by protruding into openings in the sides of the housing, as illustrated in FIG. **19**. Therefore, the spring **427** tends to push the front face **419** of the first ferrule barrel **405** into contact with the ledge **117**. The spring **427** can be compressed when the ferrule tip **45** is contacted by another ferrule tip of a mating connector, thereby permitting the front face **419** of the first ferrule barrel **405** to leave the ledge **117**.

Rotation of the tube **423** within the extender **125**, e.g., by a tool engaged to the two notches **471**A and **471**B, causes corresponding rotation of the second ferrule barrel **406** (due to the connection at **469**) and the ferrule **40** (due to the second coefficient of friction, or epoxy attachment) relative to said first ferrule barrel **405**. In one embodiment, the first and second ferrule barrels **405** and **406** and the tube **423** may be formed of metal. The tube **423** may alternatively be formed of a rigid and strong plastic.

FIG. **17** is a front view of the connector housing **109** and best illustrates the front face **419** of the first ferrule barrel **405** when fully seated into the cavity **113**, i.e., in abutment with the ledge **117** within the cavity **113**. The recessed portions **421** and **421'** are accessible through the opening **21** in the front face **110** of the connector housing **109**, and can be engaged by a tab of a tabbed alignment sleeve within an adapter, as noted above, to provide precise rotational alignment in the mating of satellite cores while still enabling the ferrule **40** to be pressed rearwardly into the connector housing **109**.

FIG. **18** shows a modified MCF connector **401'**, based on the fourth MCF connector **401** of FIGS. **16-17**. The modified MCF connector **401'** is the same as the fourth MCF connector **401**, except that the rigid tube **423** for causing rotation of the second ferrule barrel **406** has been replaced with a tradition tube **123**, which need not be rigid/strong and does not include any feature, e.g., notches **471**A and **471**B, for engagement by a tool to cause rotation of the tube **123**.

In this alternative embodiment, the second ferrule barrel **406'** is rotated by teeth **408**. In particular, teeth **408** are attached to an exterior, peripheral surface of the second ferrule barrel **406'**. An opening **410** in a side of the connector housing **309** provides access to the teeth **408**. Other than the opening **410**, the connector housing **309** may be formed the same as connector housing **109** of the first embodiment. The teeth **408** may be engaged by a tool through the window **410** to impart a rotation to the second ferrule barrel **406'** and cause the second ferrule barrel **406'** to rotate the ferrule **40** in order to cause a desired angular alignment of cores of the multi-core fiber **103** relative to the first ferrule barrel **405**, which is captured within, and not permitted to rotated by, the notches **115**A through **115**D inside the cavity **113** of the connector housing **309**. The first and second ferrule barrels **405** and **406'** may be formed of metal. The tube **123** may be formed of a flexible plastic.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are to be included within the scope of the following claims.

The invention claimed is:

1. A multi-core fiber connector comprising:

a ferrule;

a multi-core fiber secured within said ferrule;

a ferrule barrel surrounding at least a portion of said ferrule, said ferrule barrel including at least one spline extending away from an outer peripheral surface of said ferrule barrel; and

a connector housing having an inner cavity receiving said ferrule barrel, said inner cavity including at least one notch receiving said at least one spline and permitting said at least one spline to move within said at least one notch in a first direction which is substantially parallel to an extension direction of said ferrule.

2. The connector of claim **1**, wherein a width of said at least notch is not more than 0.003 inches greater than a width of said at least one spline, so as to permit reciprocal movement of said ferrule barrel along an axis passing through the center of said ferrule, which is parallel to the first direction, and limit rotation of the ferrule barrel around the axis to less than +/−2.3 degrees.

3. The connector of claim **1**, wherein said at least one spline includes four splines, each extending away from said outer peripheral surface of said ferrule barrel and being equally spaced around said peripheral surface of said ferrule barrel at intervals of ninety degrees.

4. The connector of claim **1**, wherein said ferrule is cylindrical in shape and includes a central bore possessing said multi-core fiber.

5. The connector of claim **1**, wherein a face of said ferrule barrel, which is substantially perpendicular to the extension direction of said ferrule, includes a recessed portion to receive a tab of a sleeve in an adapter.

6. The connector of claim **1**, further comprising:

a tube surrounding the multi-core fiber exiting said ferrule;

an extender surrounding said tube; and

a spring surrounding said tube and residing between said ferrule barrel and said extender and biasing said ferrule barrel away from said extender, wherein said extender is attached to a portion of said inner cavity of said connector housing.

7. A multi-core fiber connector comprising:

a ferrule;

a multi-core fiber secured within said ferrule;

a ferrule barrel surrounding at least a portion of said ferrule, said ferrule barrel including at least one spline extending away from an outer peripheral surface of said ferrule barrel;

a strength member surrounding the multi-core fiber to a rear of said ferrule barrel, said strength member including at least one notch receiving said at least one spline and allowing said at least one spline to move in a direction substantially parallel to an extension direction of said ferrule;

a connector housing having an inner cavity receiving said ferrule barrel and said strength member, wherein said strength member is attached directly or indirectly to said connector housing.

8. The connector of claim **7**, further comprising:

an extender surrounding said strength member, and wherein said strength member is adhered to said extender, and said extender is attached to a portion of said inner cavity of said connector housing.

9. The connector of claim **7**, further comprising:

a tube located between said strength member and the multi-core fiber to the rear of said ferrule barrel; and

a spring surrounding said tube and residing between said ferrule barrel and a portion of said strength member and biasing said ferrule barrel away from said portion of said strength member.

10. A multi-core fiber connector comprising:

a ferrule;

a multi-core fiber secured within said ferrule;

a ferrule barrel surrounding at least a portion of said ferrule, said ferrule barrel including first and second splines extending away from an outer peripheral surface of said ferrule barrel;

a first collar surrounding said ferrule on a first side of said ferrule barrel, said first collar including first and second notches to receive said first and second splines and allowing said first and second splines to slide therein, said first collar including first and second tabs protruding away from a surface of said first collar;

a second collar surrounding said ferrule, said second collar including third and fourth notches to receive said first and second tabs and allowing said first and second tabs to slide therein; and

a connector housing having an inner cavity receiving said second collar, wherein said second collar is adhered to said inner cavity.

11. The connector of claim 10, further comprising:

an extender surrounding said multi-core fiber to a rear of said ferrule barrel, said extender being located on an opposite side of said ferrule barrel as compared to said first collar, wherein said extender is attached to said inner cavity of said connector housing.

12. The connector of claim 11, further comprising:

a spring interposed between said ferrule barrel and said extender.

13. The connector of claim 10, wherein said ferrule barrel, said first collar and said second collar are all formed of metal.

14. The connector of claim 10, wherein said first and second splines are located approximately one hundred eighty degrees apart along said periphery of said ferrule barrel, and wherein said first and second tabs are located approximately one hundred eighty degrees apart along said edge of said front face of said first collar, and wherein the first and second tabs are offset by approximately ninety degrees relative to the first and second notches.

15. The connector of claim 1, wherein said ferrule barrel is a first ferrule barrel and said portion of said ferrule is a first portion of said ferrule; and wherein said first ferrule barrel is pressed fitted onto said first portion of said ferrule, such that said ferrule can turn within said first ferrule barrel once a first frictional coefficient existing between said ferrule and said first ferrule barrel is overcome.

16. The connector of claim 15, further comprising:

a second ferrule barrel surrounding at least a second portion of said ferrule, wherein rotation of said second ferrule barrel causes said ferrule to rotate within said first ferrule barrel.

17. The connector of claim 16, wherein said second ferrule barrel is pressed fitted onto said second portion of said ferrule, and wherein a second frictional coefficient exists between said ferrule and said second ferrule barrel, and wherein the second frictional coefficient is greater than the first frictional coefficient.

18. The connector of claim 16, wherein said second ferrule barrel is adhered to ferrule.

19. The connector of claim 16, further comprising:

a tube attached to said second ferrule barrel, wherein said tube includes features for engagement by a tool to rotate said tube, and wherein rotation of said tube causes corresponding rotation of said second ferrule barrel and said ferrule.

20. The connector of claim 16, further comprising:

teeth attached to an exterior of said second ferrule barrel; and

a opening in a side of said connector housing providing access to said teeth, wherein said teeth may be engaged to impart a rotation to said second ferrule barrel and cause said second ferrule barrel to rotate in order to cause align of cores of the multi-core fiber.

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